Application of ITEP-TWAC Accelerator Beams for Diagnostics of Fast Process.

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Abstract. Parameters of the proton radiographic facility which constructed on the ITEP TWAC accelerator for diagnostic static objects and fast process are reported. Time structure of accelerator beam is able to make a diagnostic of dynamic process with characteristic speed up to
20 km/s.

Introduction

Method of radiographic study of matter is the unique experimental technique for absolute measurements of important material characteristics of dense non-transparent objects in super high-speed processes. The X-Ray radiography (including synchrotron radiation radiography [1]) is more prevalent in a practice of the experimental research of extreme states of matter. At the same time, radiographic study with the use of high-energy charged particle beams [2] has high spatial and time resolution, better penetration capability and wider dynamic range of image registration in comparance with the X-Ray technique. Also, this technique can provide a multi-frame registration of dynamic processes that gives the ability to trace time evolution of studied parameters and states of matter.

The 800-MeV proton radiography facility for shock-wave and detonation studies in condensed matter is under development at the ITEP Terawatt Accelerator (TWAC-ITEP) [3] at present time. The first dynamic explosive experiments on the registration of density distribution in steady-state detonation waves in pressed TNT charges were performed on this facility in 2008. As it is known from our studies with VISAR laser interferometer, in pressed TNT with initial density of 1.4 g/cc and lower the duration of chemical reaction zone and corresponding area of high pressure (“Von Neumann spike”) amounts to ~200–250 ns, which corresponds to the reaction zone width of ~1–1.5 mm. Therefore the samples with initial density of 1.30–1.35 g/cc, the diameter of 15 and 20 mm and the length of 32–40 mm were studied. Detonation in samples was initiated by a point source, i.e. by an electro detonator in active high explosive charge. Total weight of studied TNT samples with active charges didn’t exceed 25 g.

The 800 MeV proton beam intensity from the TWAC-ITEP accelerator in those experiments was about 10^{10} particles per pulse. The proton beam bunch duration was equal to 800 ns. A single beam bunch consisted of four consequent 70 ± 5 ns long micro bunches with 250 ± 15 ns intervals between them. It potentially enabled to register up to four proton radiography images of studied processes during a single accelerator cycle. In our case high-speed CCD cameras with the synchronization with a single proton bunch from accelerator provided a registration of radiographic images.

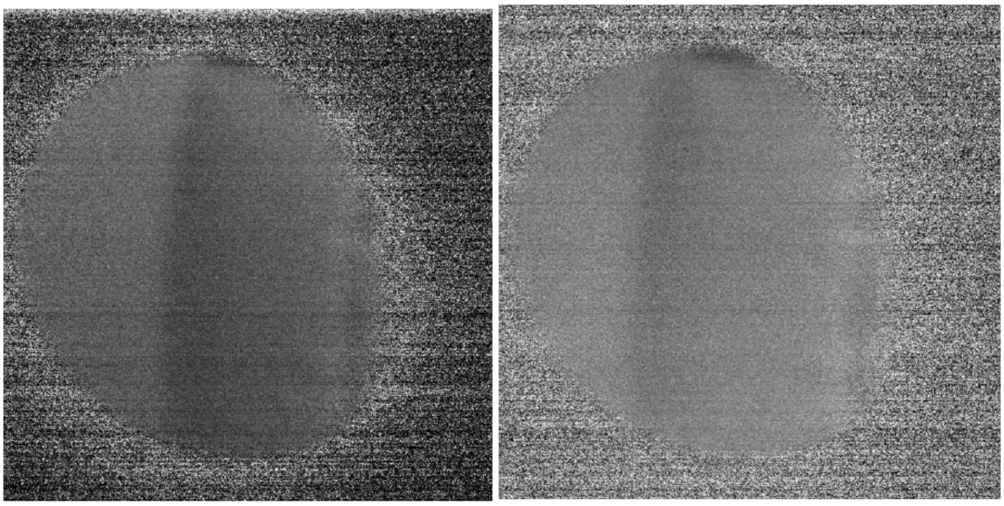

FIG.. 1: Proton radiography images of detonation wave in detonated TNT charge for two consecutive proton bunches with the interval of 250 ns: left image — first bunch; right image — second bunch.

The radiographic images of detonated TNT charges for two consecutive proton bunches were obtained in these experiments. Two of those are presented in Fig. 1. The vertical dark strip observed in the center of each image corresponds to the zone of compression of matter in deto nation wave. The estimated velocity of strip displacement between two frames is 7.76 km/s, which is notably higher than the detonation velocity of TNT at this initial density, i.e. 6 km/s. It can be attributed to the uncertainty of the position of compression zone due to strong blurring of its boundary.

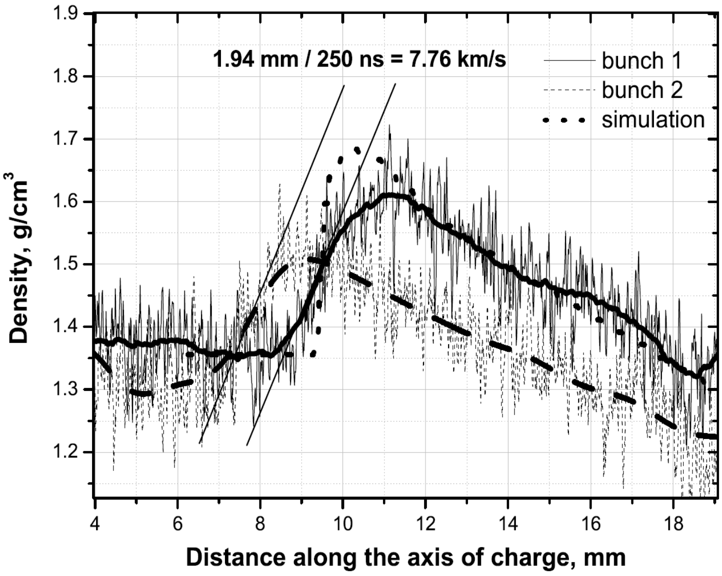

FIG. 2: Volume density profiles along the axis of TNT charge corresponding to two consecutive proton radiography images shown in Fig. 1. Dotted line is 2D computer simulation.

Volume density profiles corresponding to the images shown in Fig. 1 are presented in Fig. 2 along with the profile obtained from 2D computer simulation of detonation process of the similar TNT charge (dotted line). Profile 2 for the second proton bunch is located on the plot lower than profile 1 for the first bunch. It is probably connected with the residual flare of CCD matrix produced by the first shot. For this reason only profile 1 is taken into account during the further analysis.

The chemical reaction zone in detonation waves in studied TNT samples failed to be registered in the present experimental arrangement. Blurring of the registered forward front of detonation wave was found to be about 2.5 mm, which exceeded the width of the reaction zone in TNT that was about 1–1.5 mm at that initial density. From the analysis of the proton radiography images of static test targets it was shown that this value of front blurring was caused by three main reasons. The first one is the uncertainty brought by the propagation of a wave through a target during the time of the exposure of the frame that is equal to the duration of a bunch. During 70 ns the detonation wave propagating with the velocity of 6 km/s passes the distance of 420 μm. For the reduction of this factor it is necessary to carry out the registration with smaller exposures. The second one is the spatial resolution of present experimental arrangement that amounts to ~500 μm. It is two orders more than the theoretically predicted value of spatial resolution [3] as a result of the uncontrollable scattering of protons on the entrance and exit metallic windows of explosive containment chamber. For the exclusion of this factor it is necessary to pull back from the use of these windows in experiments. The appropriate modernization of the facility is planned on the next stage of the work.

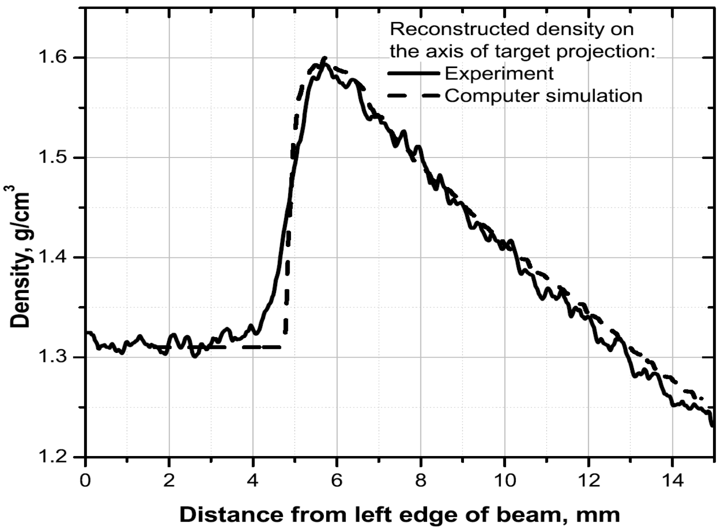

FIG. 3: Density profiles on the axis of detonating TNT charge: solid line - experimental profile for the detonation wave at the transition from the charge with diameter of 20 mm into the charge with diameter of 15 mm; dashed line - simulation for a charge with 20 mm diameter.

The third factor that is causing the blurring of the registered detonation wave front is the influence of lateral unloading on the boundary between the charge and the external environment that noticeably warps the front form. For the reduction of this influence the waves with greater front curvature that would enable the observation of undistorted wave without the unloading directly on the axis of the charge or, on the contrary, flatter waves in which the influence of lateral unloading would be noticeably weaker could be studied. In this connection the separate experiments on propagation of detonation waves through targets composed from TNT charges of different diameters were carried out. Their results are presented in Fig. 3. Immediately after the transition of detonation wave from the charge with the diameter of 20 mm into the charge with the diameter of 15 mm the wave with front curvature that is less than that in the uniform 15 mm charges was observed. Blurring of the forward front of the wave in this case amounted to 1.5 mm which is substantially less than its initial value. Further experiments with composite charges will be conducted on the next stage of the work.

Nevertheless, as it is shown in Fig. 2, the obtained volume density profiles show not only qualitative, but also good quantitative agreement with literary data and simulation results for the propagation of detonation wave in TNT charges of studied densities in the region of unloading. For example, the density of detonation products in the Chapman–Jouget point amounts to ~1.7 g/cc for given initial density [4], while the value of density peak on profile 1 in Fig. 2 which in accordance with the above is located beyond the boundaries of chemical reaction zone is equal to 1.6 g/cc.

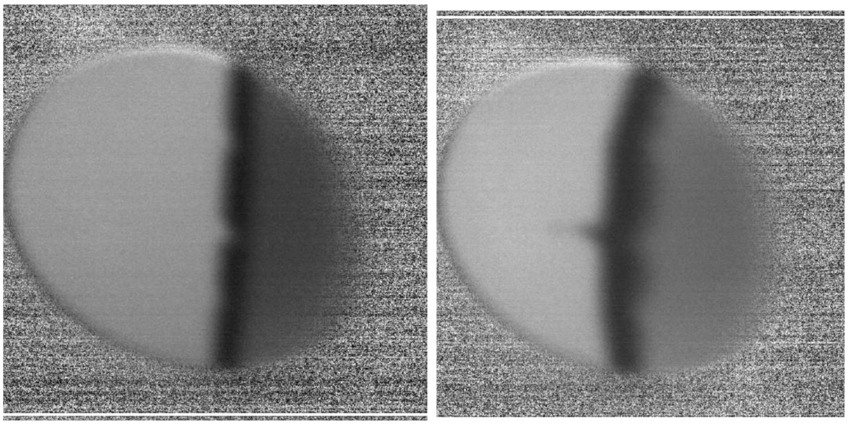

FIG. 4: Proton radiography images of steel plate with notches placed at the face of TNT charge: top – static: bottom – shot after 1 μs after the coming of shock wave to the free surface of plate.

Apart from detonation wave studies in TNT samples the experiments on the observation of ejecta formation on metal surfaces under shock wave loading were performed. 1mm thick steel plates with 0.3 and 0.5 mm deep triangular notches were placed on faces of TNT charges. Proton radiographic image of each target was taken after 1 μs after the shock wave in steel plate generated by detonation wave in TNT had come to free steel plate surface. The experimental results are presented in Fig. 4. On the obtained images the stream of ejected metal particles that moves with far greater velocity than the plate surface is observed at the location of 0.5 mm notch, although at locations of 0.3 mm notches such streams are not visible. Free surface velocity of steel plate estimated from its displacement between two shots separated y the interval of 250 ns amounts to 1.68 km/s. Estimated velocity of the head of ejecta is equal to ~4 km/s.

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